Towards a Cloud of Things Smart City

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1. Introduction

Cities are growing steadily and urban living poses major challenges in our daily lives. In this context, Information and Communication Technologies (ICT) together with local governments and private companies, play a key role for implementing innovative solutions, to make smart cities a reality. In this context, the Internet of Things (IoT) is an enabler for a broad range of applications and services. The IoT goes through a larger and larger set of heterogeneous devices able to join the Internet spread within the cities among the citizens. It now makes sense to consider the scenario of these heterogeneous devices interconnected to each other and to exploit their synergy by involving their sensing and actuation resources in the Cloud. Nevertheless, there are still some challenges to face such as: 1) the interoperability among different ICT systems; 2) a huge amount of data to be processed provided in real-time by the IoT devices deployed in the smart systems; 3) the significant *fragmentation* deriving from the multiple IoT architectures and associated middleware; 4) heterogeneous resources mashup, namely how to orchestrate resources of the various Clouds. Concerning the last item, the concept of IoT, with underlying physical objects abstracted according to thing-like semantics, seems a valid starting point for the orchestration of the various resources. In this context, the Cloud concept could play the role to connect the IoT with the *Internet of People* through the *Internet of Services*, by the means of a horizontal integration of various silos.

In this paper, we introduce the concept of the Cloud of Things (CoT), starting from the traditional Cloud computing concept (Section 2). The CoT concept goes beyond the interconnection and hyperlink of things. It is a horizontal integration of different IoT networks silos and the associated cloud computing. The development of the convergence of diverse IoT platforms and Clouds goes through implemented abstraction, virtualization and management of things. A precise design of these mechanisms will permit the development of a technological-agnostic architecture, where the integration and deployment of diverse devices and objects can be considered by neglecting their underlying architecture. Based on the requirements a smart city should fulfill (Section 3), we show how the combination of IoT and CoT can make the cities smarter and more sustainable. We illustrate the Cloud of Things concept through the description of the VITAL architecture developed in the framework of the FP7 VITAL project, a CoT-based architecture, able to meet many critical requirements of a smart city, and we will show how this platform can be considered to bridge different and heterogeneous IoT silos and be effective solution to be applied for the realization of a smart city (Section 4).

2. Toward a Cloud of Things

Cloud Computing attracts the attention from both academy and industry across the world, thanks to its ability of transforming service provision models over the entirely current IT industry with reduced upfront investment, expected performance, high availability, fault-tolerance, infinity scalability, and so on. The services can be divided in three layers [12]:

- *Infrastructure as a Service (IaaS)* which offers computing resources such as processing or storage;
- *Platform as a Service (PaaS)* to allow software developers to write their applications according to the specifications of a particular platform independently of the underlying hardware infrastructure;
- *Software as a Service (SaaS)*, the most visible layer for end-users, focuses on the actual software applications accessed and used.

In addition to the above main layers, some others are also introduced and discussed in literature such as Data as a Service (DaaS), Network as a Service (NaaS), Identity and Policy Management as a Service (IPMaaS). In [2] authors introduce XaaS (everything as a service model) that promotes the *pay as you go* method, allowing the consumption of a service by paying only for the amount of resources used. Within the IoT context, such an approach leads to the Cloud of Things [9], which deals to implement indexing and querying services of *things*, and provides them to final users, developers, provides. One interesting model to enable a CoT [13] focuses on the *Sensing as a Service (SeaS)* model based on IoT infrastructure, relying on four conceptual layers (See Fig. 1):

- *Sensor and Sensor Owners Layer:* sensors and how to manage them with possible publication in the cloud.
- *Sensor Publishers* to detect available sensors and get permission to publish them in the cloud.
- *Extended Service Providers* to select sensors from multiple publishers based on customer's requirements.
- *Sensor Data Consumers* that need to register to consume sensors data.

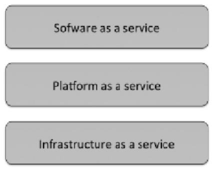

Figure 1 Cloud Computing service models [12]

The advantages and benefits promised by the *Sensing as a Service* model are numerous, and just to name the majors we have: *sharing and reusing of sensor data* (if someone has already deployed the sensors, others can get access to them by paying a fee to the sensor owner), *reduction of data acquisition cost* due to the shared nature, *collect data previously unavailable* (thanks to the business model, companies are stimulated to "sell" them sensors data). In the last few years, researchers have mainly focused on representing the observation and measurement data from sensor networks, according to the Sensor Web Enablement (SWE) proposed in [4] by the Open Geospatial Consortium (OGC). However, these standards do not provide facilities for abstraction, categorization, and reasoning rather offered by [7], within the W3C Semantic Sensor Network Incubator group (SSN-XG) defined an OWL2 ontology, answering the need for a domain-independent and end-to-end model for sensing applications by merging sensor-focused (e.g. SensorML), observation-focused and system-focused views. It has received consensus of the community and has been adopted in several projects like Spitfire EU Project. Solutions handling heterogeneous communications for resource-constrained devices are provided by 6LoWPAN and CoAP [8]. 6LoWPAN allows the integration of sensor to the Internet thanks to transmission of IPv6 packets. In order to convert IPv6 packets to 6LoWPAN and vice versa, a gateway (i.e. border router) takes care of the necessary tasks such as header compression and enables the seamless usage of IPv6 across the heterogeneous network architectures. CoAP is an application layer protocol designed for energy-constrained devices. It deals with Constrained RESTful Environments (CoRE) [16], providing a lightweight alternative to HTTP. Devices supporting CoAP provide flexible services over any IP network using UDP. Any HTTP client or server can interoperate with CoAP-ready endpoints by simply installing a translation proxy between the two devices [6]. Summing up, IoT devices can be connected to the Internet, their data can be annotated using a sensor ontology (i.e., SSN ontology), encoded in standard Web formats (i.e., RDF), and made available on the Cloud, establishing therefore the *Cloud of Things*.

3. Smart City Requirements

As remarked in [1], the main ICT-based services and solutions requirements in the Smart City domain can be classified as: 1) *service/application*, considered from the point of view of the citizens and 2) *operational*, seen from the city authorities and administrators of the networks point of view. Concerning the *service/application* aspects, the end-users devices equipped with multiple radio technologies and the several sensors and actuators deployed all over the cities, make possible the individuation of novel services and applications for the citizens. These services will have specific features, like: a) *user-centric*: based on the specific context and the preferences of the users, b) *ubiquitous*: reachable everywhere and from any devices, and c) *highly-integrated*: based on the integration of services and data from several and different applications or on the social cooperation of multiple users. Of course, beyond the citizens, also the stakeholders of a city, like educational institutions, healthcare and public safety providers, governmental organizations, etc. will be in conditions to exploits the key features of these new services that make the city more sustainable. On the other hand, the Smart City concept considered from the point of view of the administrations and the providers of the networks are translated in a network infrastructure that is: a) *highly-interconnected*: by overcoming the heterogeneity of the devices and the IoT platforms, it is possible to provide ubiquitous connectivity, b) *cost-efficient*: the deployment and organization of the network should be as much automatic as possible and independent from the human intervention, c) *energy-efficient*, able to realize an efficient resource utilization, in order to meet the main requirements of *green* applications d) *reliable*: connectivity of the network should be guaranteed above all in the case of exceptional and adverse conditions. The real scenario we can currently observe is characterized with an high level of *fragmentation* of technologies, lack of ubiquity in terms of both connectivity and coverage. This *fragmentation* is mainly due to the presence of many access networks usually managed by different operators (i.e. UMTS, WiMAX, WiFi, etc.). Even if some steps ahead have been moved recently, most of these initiatives are related to specific cities and do not consider general architectures. By considering the main IoT platforms and the CoT concept, we will try to explain how the main requirements of a city to become a smart city, can be fulfilled and at the end we will show how the VITAL platform can play the role of "interconnecting" heterogeneous ICT silos and devices.

4. IoT and CoT for a Smart City

Despite there is not yet a formal and universally accepted definition of "Smart City", in [10], authors try to delineate the concept, defining a Smart City as a city which functions in a sustainable and intelligent way, by integrating all its infrastructure and services into a cohesive whole and using intelligent devices for monitoring and control, to ensure sustainability and efficiency. This interpretation makes evident, therefore, that Smart City concept needs *interoperability* between the different IoT deployments that are, today, mainly closed and vertically integrated to specific application domains [15].

These solutions are based on multiple architectures, standards and platforms, which have led to a highly fragmented IoT landscape and making challenging the realization of the Smart City concept. According to [11], the IoT structure divided into 5 layers:

- *Device Layer*: to identify and collect objects specific information by the sensor device;
- *Network Layer*: to send data collected by the Device Layer to the information processing system;
- *Middleware Layer*: to process information and take automatic decision based on the results;
- *Application Layer*: to provide global application management based on the information processed through the Middleware;
- *Business Layer*: to manage the overall IoT system.

Within the context of Smart City [5], the *Cloud of Things* can make a better use of distributed resources, achieve higher throughput and tackle large scale computation problems [14], enabling therefore, the horizontal integration of various (vertical) Internet of Things platforms and so the Smart City vision. Moreover, it allows users to express the service they want providing the relevant data back to them quickly without asking the users to manually select the sensors.

Certainly, CoT needs to deal with several research challenges, the major residing in the heterogeneity and of sensor types (e.g., NFC, RFID), and in communications (e.g. Wi-Fi, ZigBee) and their interoperability with the cloud. It is therefore important to define an *abstraction level*, in order to bridge the gap between the disparate technologies. A solution to overcome the obstacle is provided by the *data abstraction*, that includes methods and solutions to structure, annotate, share and make sense of the IoT data and facilitate transforming it to actionable knowledge and intelligence in different application domains.

Data access could be implemented at low-levels (e.g., device or network layers) using low-level programming languages and operating systems.

Regarding the various sensor type, the use of the technologies developed in the semantic web such as ontologies, semantic annotation, linked data [3] and semantic web services has recently gained momentum in this field. These technologies promote interoperability among IoT resources, information models, data providers and consumers and simplifies effective data access and integration, resource discovery, and knowledge extraction [2].

5. VITAL as a CoT-based Smart City platform

One of the most important objectives of VITAL is about the integration of sensors and interconnected objects among multiple IoT platforms and ecosystems. The project explores the convergence and federation of multiple IoT platforms by taking into account the cost efficiency of the deployments. In the context of VITAL, a very key factor is represented by the virtualization of interfaces that in combination with cross-context tools that enable the access and management of heterogeneous objects supported by different platforms and managed by different administrative stakeholders let us to define the VITAL platform as a Cloud of Things architecture.

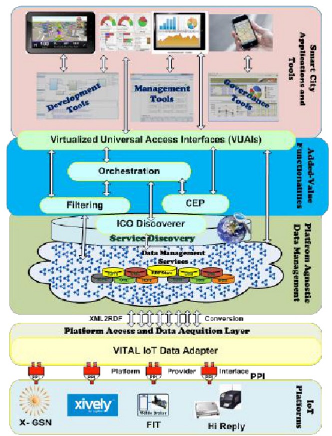

Figure 2 The VITAL platform

As we can observe in Figure 2, the data and services access of the heterogeneous objects involved in VITAL, is based on the implementation of the VUAIs (Virtualized Universal Access Interfaces), that makes possible to consider a single virtual access by making the architecture platform-agnostic. These key features of VITAL make this platform able to embrace the CoT philosophy. The VUAI layer is built upon a so-called meta-architecture and migration layer and includes several connectors to communicate and interconnect different IoT platforms and clouds. In practice, this module deals with issues related to the management of the overall VITAL infrastructure, built on top of existing IoT architectures and clouds platforms and enable heterogeneous mashup. The VUAIs allow the implementation of a kind of abstraction, where "objects" handler that point to physical items, can be discovered, selected and filtered and also allocated by following a Things as a Service (TaaS) paradigm. In this sense the VITAL as CoT platform is something that goes beyond the interconnecting and hyperlinking "things" of the IoT paradigm. VITAL also includes a datastore for data like geographical information and smart city stakeholders. Of course, it is expected that the management of this kind of information giving location awareness and other context related information can be effectively exploited in the optimization of computing and sensing of the management of the various clouds. The CoT paradigm implies the implementation of querying services and indexing of things, the aggregation of heterogeneous resources based on a given thing-like semantics and provided to the final stakeholder (final user, developer, etc.). Moreover, the CoT concept explicitly has to consider mechanisms to abstract, virtualize and manage things as performed in VITAL. It is worth to outline that VITAL is based on W3C SSN ontology, that is considered ideal as basis for unifying the semantics of different IoT platforms, since it is domain independent and extensible. Several additional concepts have to be considered to enhance the ontology starting from information about city-wide, stake-holders, IoT system, etc. The ontology update with additional functionalities will allow the migration of smart city application across different urban environments.

6. Conclusion and Future Challenges

In this paper we have shown the necessity to bridge the gap between the different IoT platforms and how the Cloud computing can stand as a valid bridge of the IoT, Internet of people through the Internet of Services. This novel perspective allows the realization of a horizontal integration of various vertical platforms like the VITAL CoT-based platform a very promising solution for the fragmentation issues in the context of Smart Cities. There are still different challenges related to the Cloud of Things in smart cities, from both technical and privacy point of view:

- *Big Data.* The overall IoT data produced by *things* is growing up fast and can be processed by *engineering* to perform data management such as query, and storage efficiently; and *semantic*, to extract the meaning of the information from massive volumes of data.
- *Privacy & Security.* One of the main problematic is to define mechanisms in order to let "sensor owners" the decision to publish or not the data. Other issues may come from the cyber-crime. The system must be prone to cyber-terrorism and cyber-vandalism.

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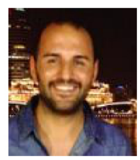

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